CEvNS Glow in LAr for DUNE

ADRYANNA MAJOR

DUKE UNIVERSITY

LEP WORKING GROUP MEETING

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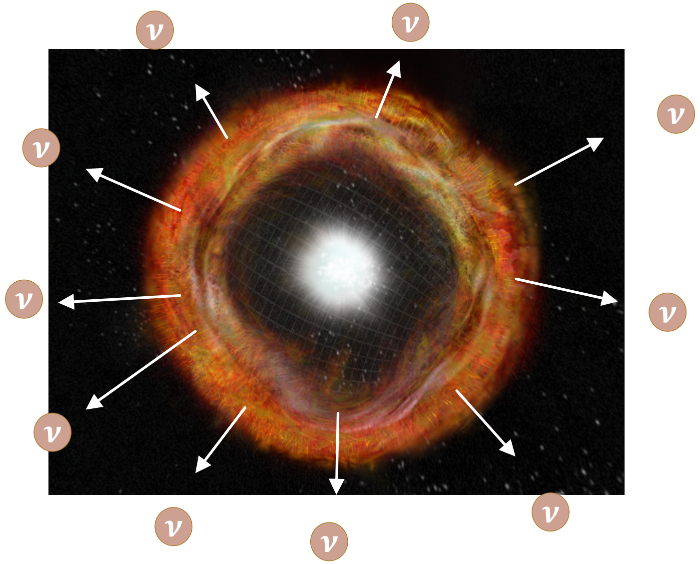
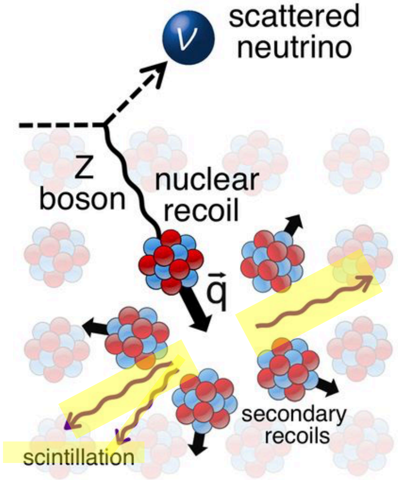
SUPERNOVA NEUTRINOS

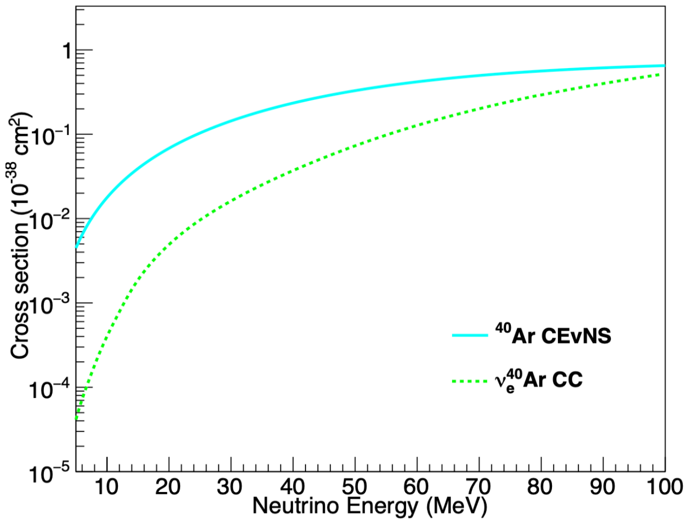
- Nearly all (99%) of gravitational binding energy in core-collapse supernovae carried away in neutrinos
  - ***All six flavors*** will be streaming out
- Arrive to Earth in a roughly ***10-second burst***, outpacing the photons' arrival $\mathcal{O}$(hours)
- Time-dependent structure of burst provides direct look into the explosion mechanism and other interesting astrophysics
- Core-collapse supernovae estimated to occur only a few times in a century within the Galaxy
  - (Important to detect as many neutrinos from a burst as we can!)



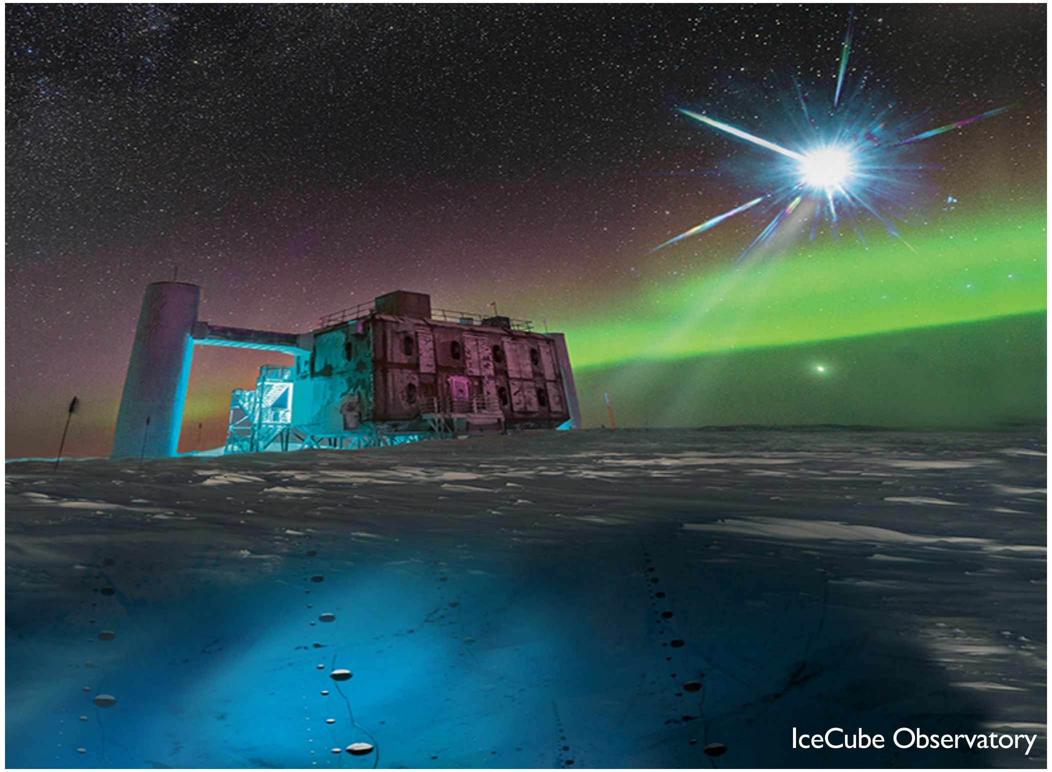
Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) interaction



- Coherent interaction up to E_ν ~ tens of MeV
- Nuclear recoil ~ few keV *(TINY!)*
- Largest cross section of low-energy neutrino couplings, but…
  - ***difficult to see scintillation from <50 keV nuclear recoil***
- Why is CEvNS good for supernova detection?
  - flavor-blind → boosts cross section, lots of events
  - critical information on the ***total flux*** of supernova burst
  - core-collapse within the Galaxy would be a high-flux source that could help circumvent "standard" CEvNS measurement limitations in dedicated small neutrino detectors



SEMI-ANALYTIC STUDY OF PHOTON DISTRIBUTION



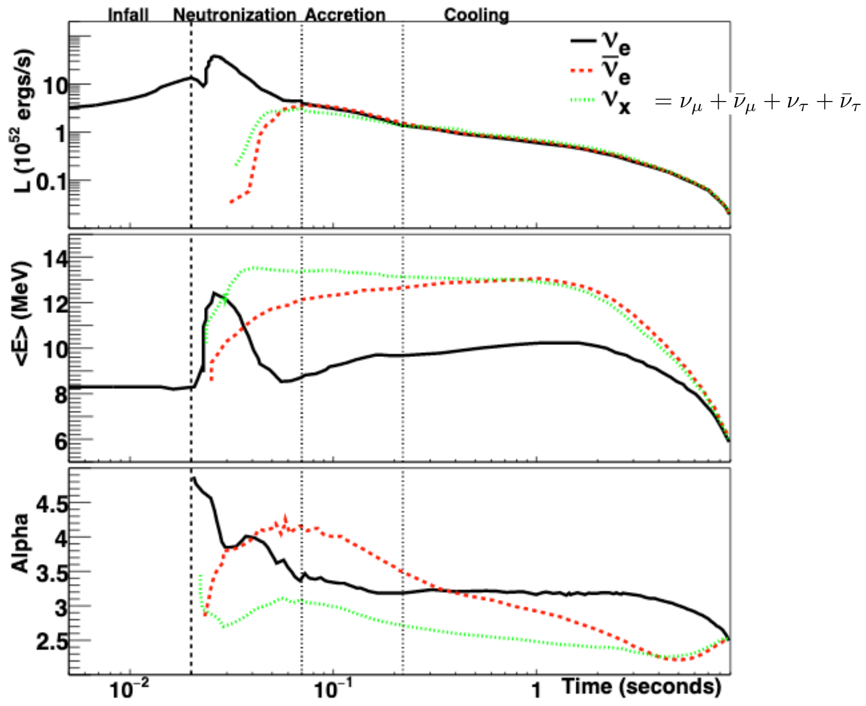
- Simulating scintillation caused by CEvNS during a 10-kpc core-collapse supernova
- The project is focused on large-scale scintillator detectors that do not have dedicated CEvNS programs, e.g. Borexino (LS), DUNE (LAr)
- The principle:
  - **During a supernova, CEvNS will dominate interactions, producing a uniform, isotropic glow throughout DUNE**
  - Can we see this glow? (given quenching, ^{39}Ar beta decay, photodetection…)

PROJECT DETAILS FOR LIQUID ARGON

- Model core-collapse supernova neutrino flux using event-rate calculator SNOwGLoBES
  - Time-dependent Garching flux (relatively cool), parameterized by avg. neutrino energy, pinching parameter (α), and luminosity:

$$\phi(E_\nu) = N\left(\frac{E_\nu}{\langle E_\nu \rangle}\right)^\alpha exp\left[-(\alpha+1)\frac{E_\nu}{\langle E_\nu \rangle}\right]$$

- Calculate CEvNS interaction rates of supernova neutrinos using dedicated code suite by K. Scholberg
- Charged-current interactions on ^{40}Ar (ν_e + ^{40}Ar → ^{40}K* + e^-) and major constant background ^{39}Ar BD are likewise calculated
- QF ~ 0.26
- LY = 24,000 photons/MeV in DUNE

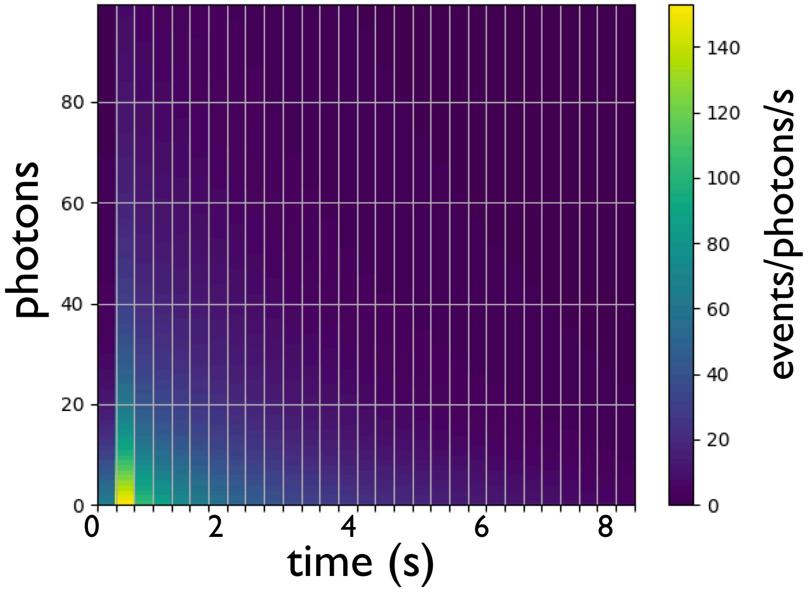


Modelled from L. Huedepohl et al., PRL 104 251101

SIGNALS IN LIQUID ARGON

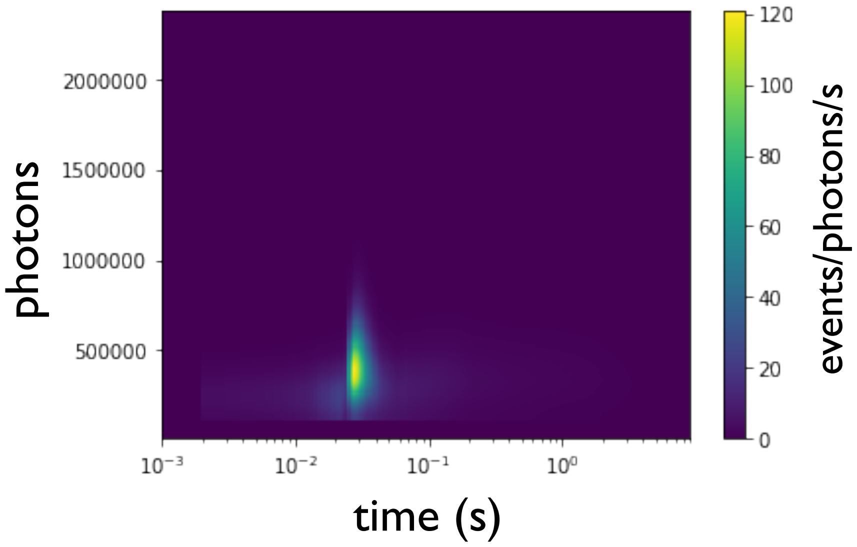
Normalized to 2.5 kT volume, assuming 24000 photons/MeV

CEvNS Photons vs. Time



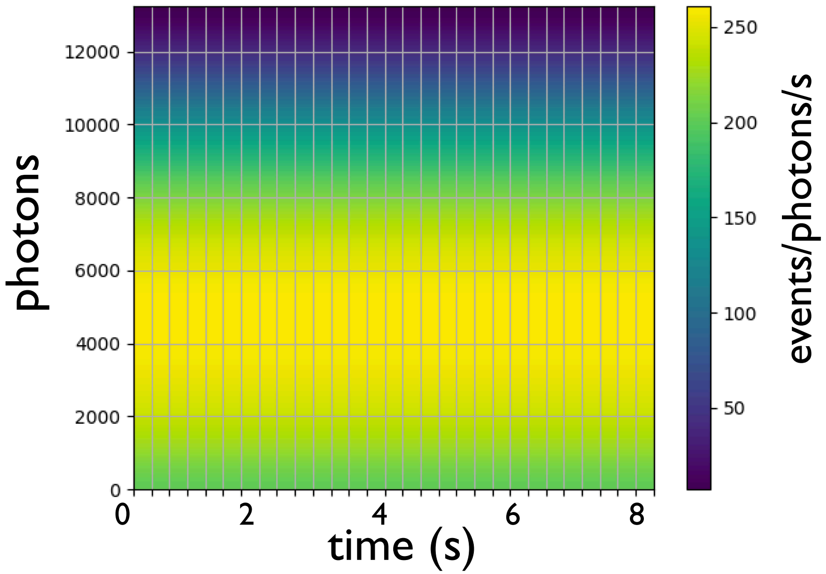
- Time-dependent structure
- Will manifest as uniform glow

Charged Current Photons vs. Time



- CC will be sharp events
- Trigger-able on their own

Ar39 Beta Decay Photons vs. Time



- Constant in time
- Controlled by purity of LAr

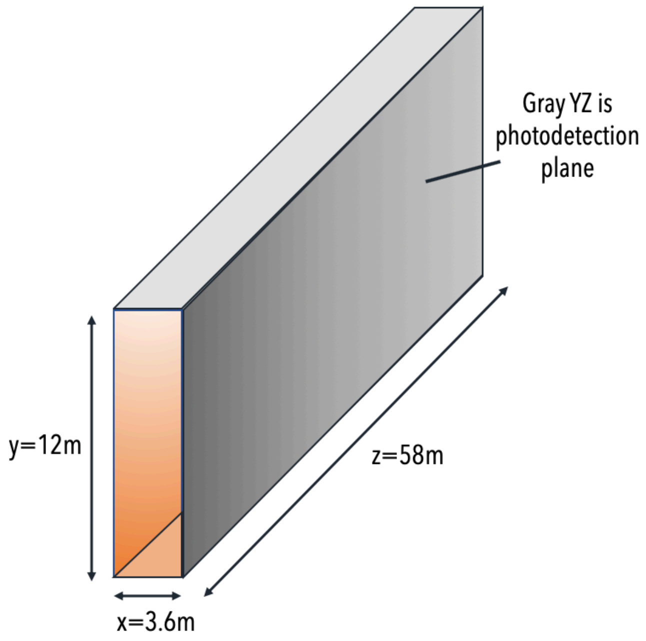
*note: photons axis is independent of gridlines here

SIMULATING PHOTON DIFFUSION

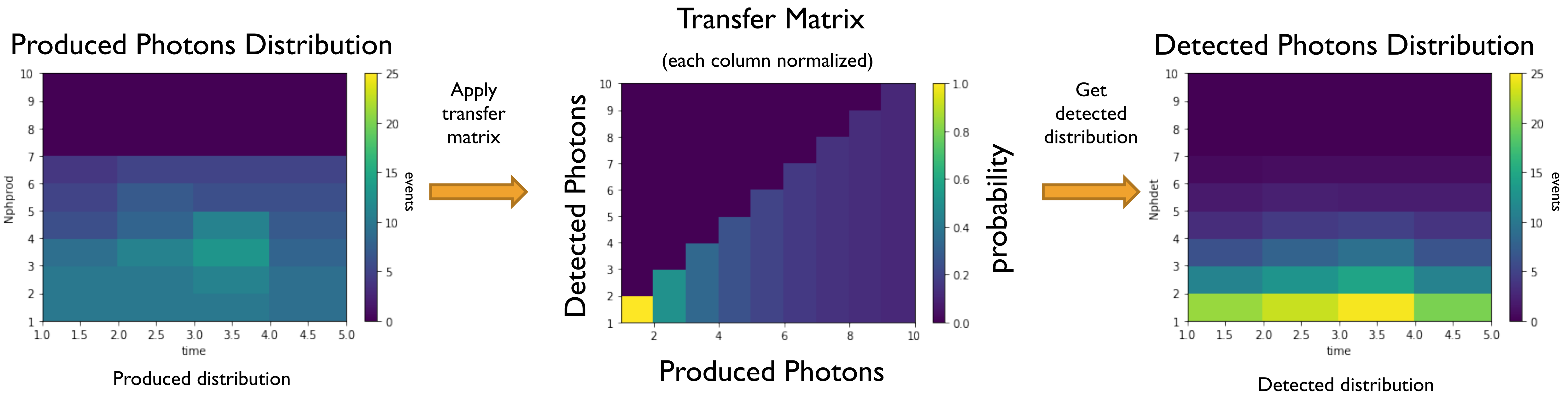
- Semi-analytically calculate photon diffusion within one 2.5-kT drift-length volume of DUNE FD
  - Method of images in Python—no LArSoft used
  - Idea outlined by V. Galymov (DUNE SP-DP Consortium talk Feb 11, 2017)
- Treat entire APA plane as photosensitive
- Create transfer matrix using acceptance probabilities of photons on APA
- Use transfer matrix to obtain detected photon distribution within given detector geometry & scintillator material

$$\frac{\partial}{\partial t} p(x,t) = D \frac{\partial^2}{\partial x^2} p(x,t)$$

$$\int dt \int_{\Omega} \boldsymbol{dA} \cdot D\nabla p$$



EXAMPLE APPLICATION OF A TOY TRANSFER MATRIX

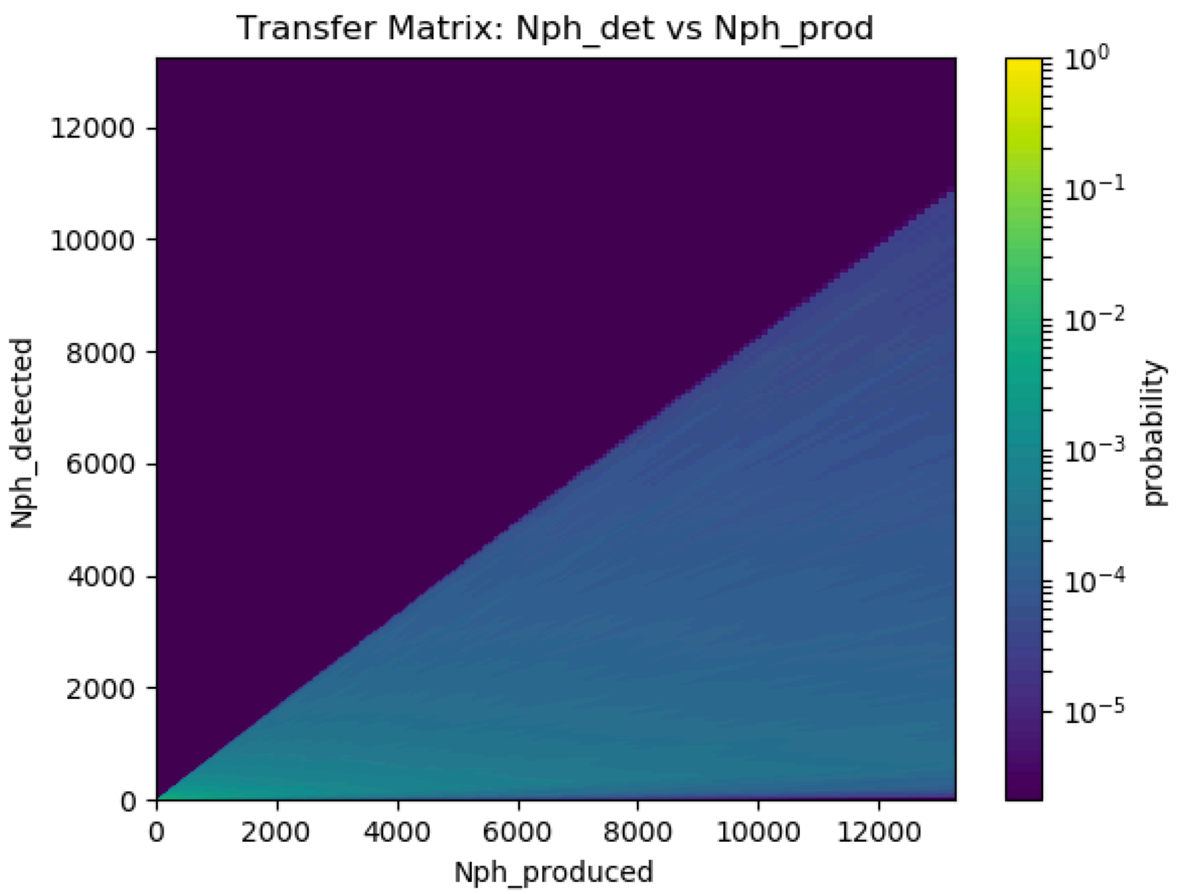


Allows multiple-photon signals to now be processed via matrix multiplication

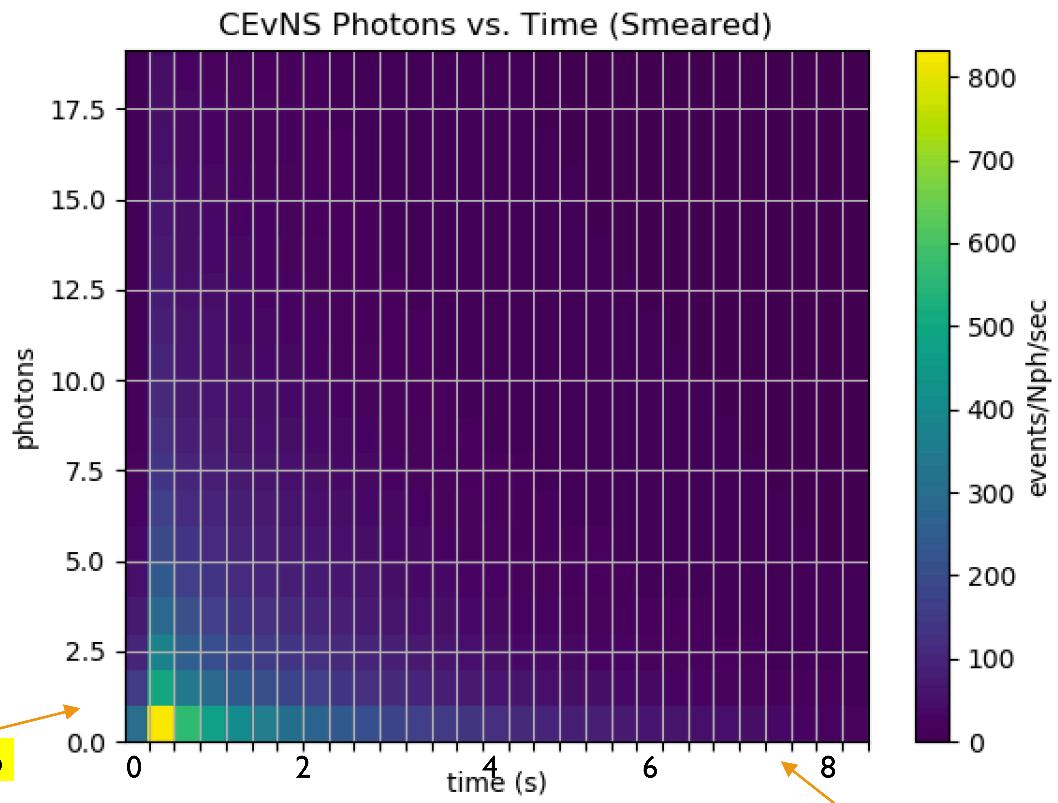
SO PUTTING THIS ALL TOGETHER

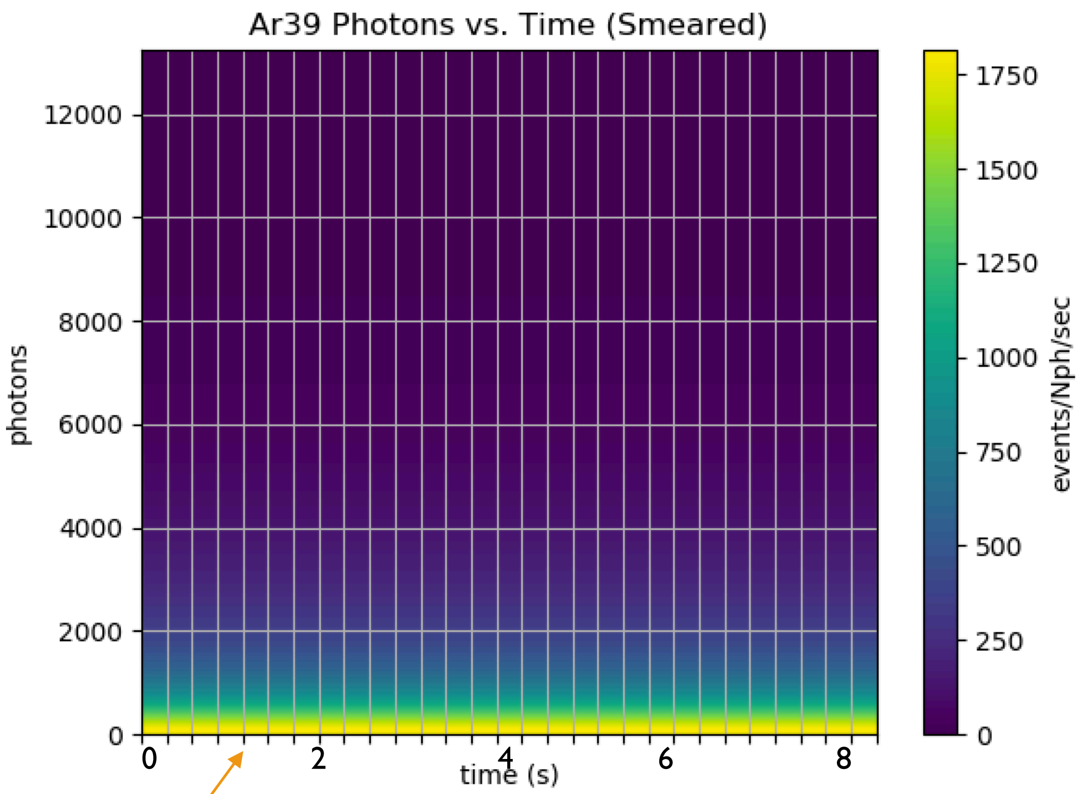
TRANSFER MATRIX IN LIQUID ARGON

- Smears photon distribution downward based on probability of photon reaching PD plane



SMEARED CEνNS SIGNAL & ^{39}AR BETA DECAY





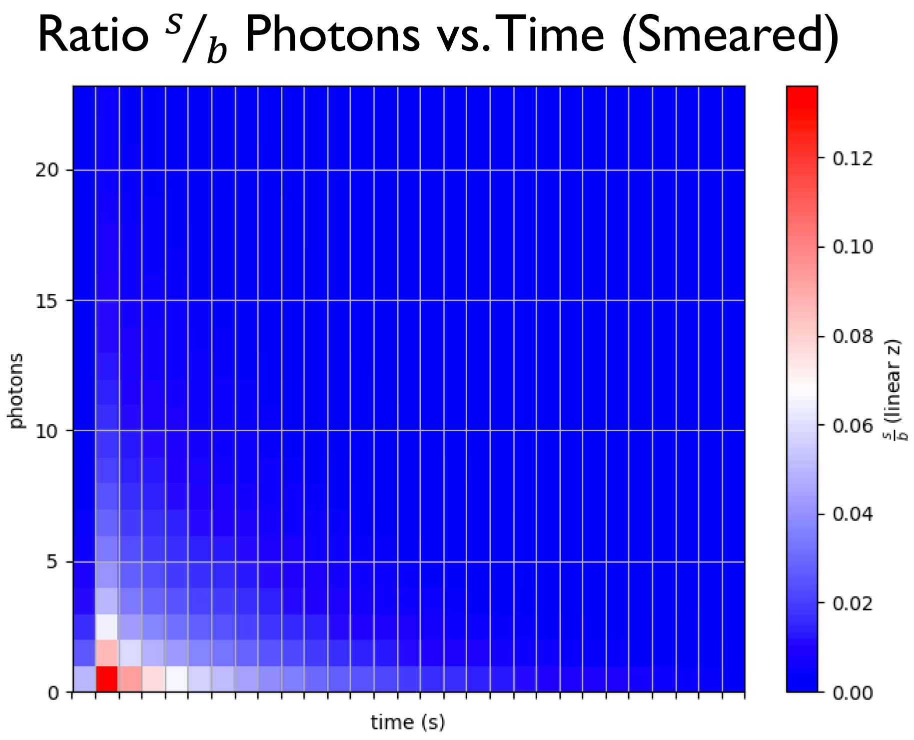
Concentration towards single- to few-photon bins

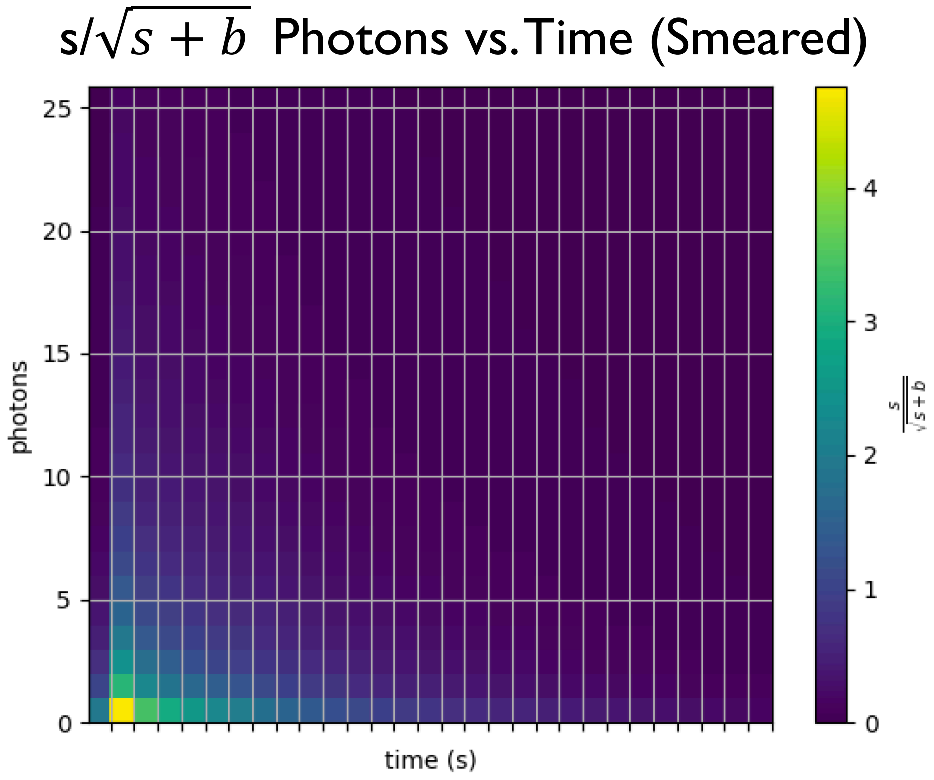
After applying transfer matrix

*note: photons axis is independent of gridlines here

RATIO CEνNS / AR39 & SENSITIVITY

s = CEvNS
b = Ar39 beta decay

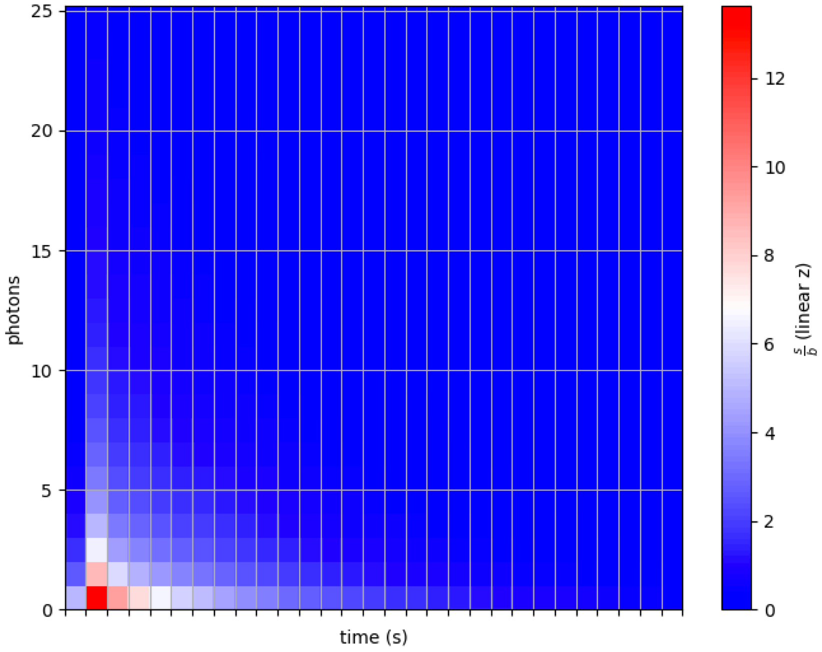




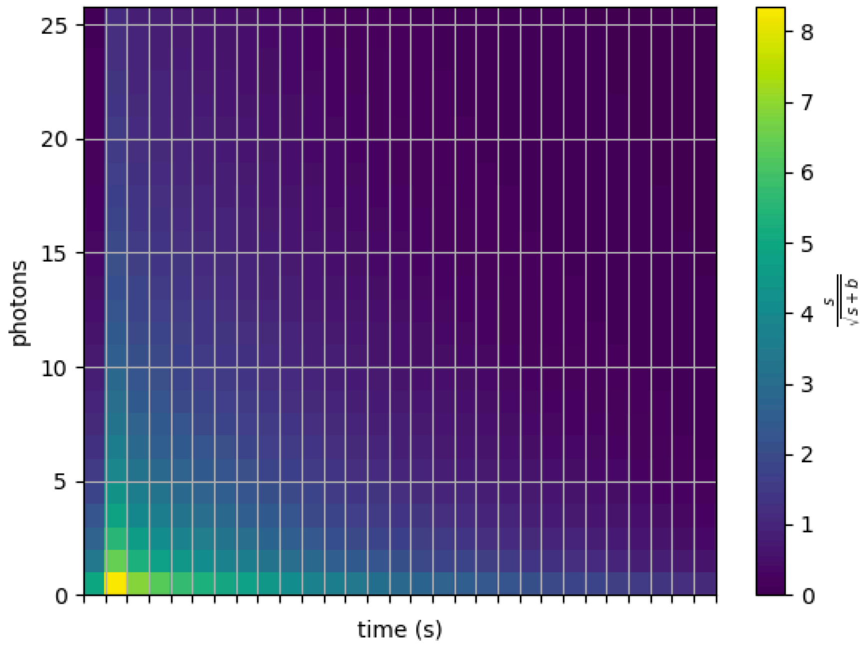
DEPLETED LIQUID ARGON

- Very conservative reduction of background by factor of 100
- (More likely would reduce by factor of 1000)

Ratio $^{s}/_{b}$ Photons vs. Time (Smeared)



s/$\sqrt{s+b}$ Photons vs. Time (Smeared)



GOING FORWARD

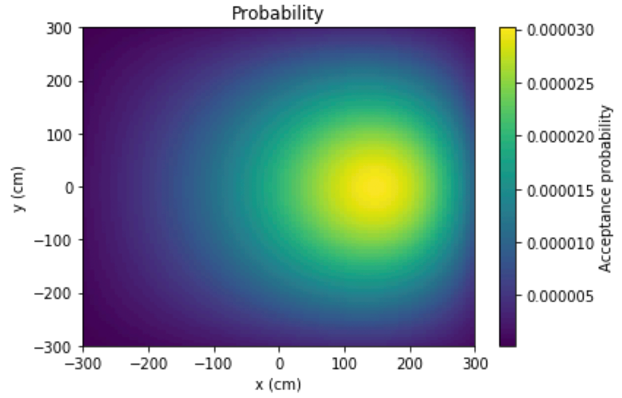
- Galactic core-collapse are rare
- DUNE has made supernova-preparedness one of its Big Goals
- A flavor-blind observation of the supernova neutrino burst's signal will help understanding of total flux
- Single PE threshold will be important for a CEvNS glow measurement
- The "glow" is only one avenue for detection—can also utilize wire data from TPCs→ "CEvNS buzz"
- 4π photosensitive volume would serve a CEvNS glow search quite well
- Viability of CEvNS glow will depend on PD area, smart triggers, PE thresholds, background reduction (depleted LAr), and long buffer size
- Paper detailing this work for LAr and organic liquid scintillator coming soon

BACK UP

PHOTON DIFFUSION

- Method outlined by V. Galymov (DUNE SP-DP Consortium talk Feb 11, 2017)
- Solve diffusion equation using method of images
- Convolve with source function (from produced photon distribution)
- Result is entirely analytic solution
  - Probability of acceptance on a plane based on source location
  - Can manipulate photon absorption, refraction wavelength, etc
  - Can easily change detector geometry (boundary conditions, Green's function)

$$\frac{\partial}{\partial t} p(x,t) = D \frac{\partial^2}{\partial x^2} p(x,t)$$



$$\int dt \int_{\Omega} \boldsymbol{dA} \cdot D\nabla p$$

Acceptance (probability photon arrives to surface)

TRANSFER MATRIX CALCULATIONS

- 3.6m x 12m x 58m
- Treating entire APA plane as photodetection surface (12m x 58m)
- Generate sources (single photon) randomly throughout volume
- Obtain probability of arriving to PD plane via analytic calculation
- Use binomial distribution to build up transfer matrix
- Multiple-photon signals now can be processed via matrix multiplication

DUNE far detector